RED DEER (*Cervus elaphus*) BARK STRIPPING ON SPRUCE WITH REGARD TO SPATIAL DISTRIBUTION OF SUPPLEMENTAL FEEDING PLACES

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Abstract

Forest damages caused by red deer and some other large herbivore species occasionally feeding on tree bark, are a grave ecological and economic problem in many parts of the world. Winter supplemental feeding is commonly used to mitigate the problem, but its effects are poorly known. This study, carried out at Pohorje (Slovenia) and including over 2,300 trees, used binary logistic regression to analyse the effects of supplemental feeding and many other factors on the probability of bark stripping on spruce. The probability of bark stripping depends on distance from the forest edge, density, age and tree species diversity of stands, slope and aspect of terrain, and red deer density; contrary to expectations, it is not related to distance from feeding places. As much as 35% of spruce trees were damaged. The damage was the highest in younger, denser pure spruce stands, whose favourable protective and microclimatic conditions (thinner snow cover, higher effective temperatures) make them a preferred winter habitat for red deer. They contain, however, little other food but bark. To prevent / diminish bark stripping we propose a stronger thinning of such stands. Supplemental feeding may reduce damage only in exceptional cases, when animals are lured and concentrated in less sensitive areas, but in general we advise against the use of this measure due to its other negative effects.

Key words: *Cervus elaphus*, red deer, bark stripping, Norway spruce, *Picea abies*, forest damages, supplemental feeding, Slovenia, environmental factors

POŠKODOVANOST SMREKE ZARADI GRIZENJA IN LUPLJENJA SKORJE PO JELENJADI (*Cervus elaphus*) GLEDE NA PROSTORSKO RAZPOREDITEV KRMIŠČ

Izvleček

Poškodbe gozdov, ki jih zaradi hranjenja z drevesno skorjo povzročajo jelenjad in nekatere druge vrste velikih rastlinojedov, so v mnogih delih sveta resen ekološki in ekonomski problem. Pogosto se ga skuša reševati z zimskim dopolnilnim krmljenjem, katerega učinki pa niso preučeni. V raziskavi, ki je potekala na Pohorju in je zajemala prek 2.300 dreves, smo z logistično regresijo analizirali vplive krmljenja in številnih drugih dejavnikov na pojavljanje poškodb smreke zaradi lupljenja. Pojavljanje poškodb je odvisno od oddaljenosti od gozdnega roba, gostote, starosti in vrstne pestrosti sestojev, nagiba in ekspozicije terena in gostote jelenjadi, proti pričakovanjem pa ne od oddaljenosti od krmišč; poškodovanih je bilo kar 35 % smrek. Zlasti so poškodovani mlajši, čisti, gosti smrekovi sestoji, saj so zaradi ugodnih varovalnih in mikro-klimatskih razmer (plitvejša snežna odeja, višje efektivne temperature) priljubljen zimski habitat jelenjadi, v katerem pa razen skorje skoraj ni hrane. Za preprečevanje poškodb zato svetujemo močnejša redčenja takih sestojev. S krmljenjem je verjetno škode mogoče zmanjšati le izjemoma, kadar z njim živali odtegnemo na manj občutljiva območja, sicer pa rabo tega ukrepa zaradi drugih negativnih učinkov v splošnem odsvetujemo.

Ključne besede: Cervus elaphus, jelenjad, lupljenje, smreka, Picea abies, poškodbe sestojev, dopolnilno krmljenje, Slovenija, okoljski dejavniki

INTRODUCTION AND PURPOSE OF THE STUDY
UVOD IN NAMEN RAZISKAVE

Red deer (*Cervus elaphus*) and several other species of large herbivores (overview in VERHEYDEN *et al.* 2006), which can feed on tree bark (i.e. peeling off and biting bark of trees), can cause grave economical and ecological damage in forests, which is a serious problem in many parts of the world. By interrupting conducting tissue, stripping can directly result in tree mortality; damage to the bark exposes the tree to fungi and other pathogenic organisms that cause wood discoloration and decay, stem deformation and tree mortality; the mechanic stability of stands (i.e. resistance to snow, sleet and storm) can be significantly impaired (*ibid.*). Bark stripping can thus directly and indirectly reduce the survival of trees (e.g. PARKS / BEDNAR / TIEDEMANN 1998) and, consequently, affects forest composition in terms of species and tree diameter representation as well as the structure and dynamics of entire forest ecosystems (e.g. YOKOYAMA *et al.* 2001). Furthermore, it can significantly reduce the volume and, in particular, the value increment of stands, resulting in severe economic losses (BENCZE 1977, SIMON / KOLAR 2001). In Europe, including Slovenia, bark stripping is mo-

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stly caused by red deer, in particular in younger, often even-aged spruce stands (VERHEYDEN *et al.* 2006, KIFFNER *et al.* 2008); examples in Slovenia include Kočevska, Gorenjska and Pohorje (ČAMPA 1986, ŠKULJ 1987, DAJČMAN 2008).

Slovenia and several other European countries commonly attempt to alleviate bark stripping damage with winter supplemental feeding (PUTMAN / STAINES 2004). Belief about the efficiency of this measure rests primarily on the logical conclusion that adding supplemental food reduces the consumption of natural food sources, including bark. Yet recent telemetry studies (overview in JERINA 2006) suggest that due to supplemental feeding in the winter (when bark stripping damage is the highest) red deer start concentrating in smaller areas, around the supplemental feeding places. Furthermore, red deer become more resident throughout the year. Deer never feed exclusively at supplemental feeding places; they always get at least a part of their food in nature. In Slovenia, for example, red deer satisfy only about 5% of their annual food requirements at supplemental feeding places (ADAMIČ 1990). We therefore posit that the impact of deer on forest vegetation is higher in the proximity of supplemental feeding places, i.e. that bark stripping damage drops with distance from supplemental feeding places. Similarly, our own surveys (unpublished data) have already confirmed such conclusions for damage caused by game to forest regeneration.

The greater part of previous research on the impact of winter supplemental feeding on bark stripping has focused on studying the effects of the composition of supplemental feed and the period and extent of the feeding (e.g. UECKERMANN 1984, RAESFELD / REULECKE 1991, PUTMAN / STAINES 2004). We found only a few studies that deal directly with the effects of supplemental feeding on the extent and spatial distribution of damage (e.g. VOLK 1999, VERHEYDEN *et al.* 2006), and even these analyze rather large spatial units (for example whole regions) and have thus different goals than our study. Authors of these studies have found that supplemental feeding *per se* probably does not affect the extent of bark stripping damage (VERHEYDEN *et al.* 2006), or that feeding can reduce damage only in some areas (VOLK 1999). In general, supplemental feeding is an expensive measure, and in Slovenia, for example, it accounts for the bulk of the funds and labor invested by hunters (JERINA 2006a). Its effectiveness in reducing damage is, however, highly questionable, perhaps even contrary to general expectations; therefore its effects need to be studied much more comprehensively.

Even though supplemental feeding also pursues objectives other than reducing bark stripping damage, for example facilitating hunting and monitoring of game (see also PUTMAN / STAINES 2004), knowing its impact on the extent and spatial distribution of damage is essential for a substantive assessment of whether it is rational or not.

MATERIALS AND METHODS
MATERIALI IN METODE

STUDY AREA
OBMOČJE RAZISKAVE

The study was carried out in the Pohorje hunting district, which covers the central and eastern parts of the eponymous forested massif in northern Slovenia (E 15.399; N 46.479), at between 600 and 1,500 metres above sea level. The hunting district stretches over an area of 275 km^2, of which just over 92% is forest and the remaining 8% mostly meadows and other farmland. There are many surface waters due to the impermeable silicate bedrock and relatively strong precipitation, and wetlands in many concave areas on the upper reaches of Pohorje. The forests are largely coniferous (about 83%), most of it spruce, which often forms pure, even-aged stands. The first spruce monocultures date back to the establishment of large ironworks in the area during the 17th century. They are frequent in particular at sites of beech and mixed stands of *Cardamini savensi-Fagetum, Lamio orvalae-Fagetum* and *Luzulo-Fagetum*. After the Second World War, many problems prompted foresters to try to revert these forests to more natural mixed forms, but these efforts have borne little fruit, not least because of herbivorous game (ČAMPA 1986, ADAMIČ 1990, DAJČMAN, 2008). Pohorje is one of the bark stripping hot-spots in Slovenia. In the 1980s, when the problem of bark stripping probably reached its apex, as much as 75% of trees in younger spruce stands were damaged in the most exposed areas (ČAMPA 1986). The culling of ungulates and certain other measures subsequently reduced the damage, but they have not eliminated it completely (DAJČMAN 2008).

Pohorje has a great species variability of ungulate game. In addition to the three native species – red deer, roe deer (*Capreolus caprelus*) and chamois (*Rupicapra rupicapra*) – fallow deer (*Dama dama*) was introduced in 1968 (ADAMIČ / JERINA 2008). To add to the pressure on forest vegetation, cattle graze uncontrollably in the area in the summer,

encroaching on meadows originally maintained for deer feed (ADAMIČ 1990). Compared to most other parts of Slovenia, Pohorje has relatively high red deer and chamois densities and of all the above-mentioned species, red deer cause the majority of bark stripping damage. Red deer harvest in Pohorje hunting district (area 275 km²) amounts to 100-110 animals annually in the recent years, which corresponds to a population density of 1.2 animals / 100 ha according to Stubbe (see JERINA 2003). However, there are notable differences within the hunting district: in the north-eastern and central parts, densities are several folds above the average for the entire area, and towards the southeast they drop to ecologically negligible levels.

SAMPLING PLOTS
VZORČNE PLOSKVE

With the help of the hunting-district manager and the local hunters we geo-referenced the supplemental feeding places in the entire hunting district and recorded the type and quantity of annually supplied supplemental feed. Then we selected feeding places, which have long been well-stocked and are located in areas where the percentage of spruce is considerable. There were 6 such feeding places, at which an average of 100 tonnes of marc and 19 tonnes of hay were provided to red deer annually (DAJČMAN 2008). Locations of these feeding places were used as the basis for setting the sampling plots as described hereinafter.

For each supplemental feeding place we selected a random direction of the first transect and the remaining three at 90-degree angles to each other. We opted for random selection of direction and four sampling transects instead of one around each supplemental feeding place in order to eliminate the impact of spatial variables that vary in gradient over large distances (e.g. altitude, red deer density). Due to the perpendicular orientation of the sampling transects, their effects eliminated each other in averages, at least to a certain degree. On each sampling transect we fixed in the GIS environment the preliminary locations of six sampling plots that are spaced in 300-metre intervals from the supplemental feeding place up to a distance of 1,800 metres. The final distance was chosen based on our own previous telemetry surveys (JERINA 2003, 2006) which showed that the probability of annual use of space by red deer gradually declines up to a distance of about 1,500 metres from a supplemental feeding place, whereupon is stabilises. Indeed, in the winter red deer tend to concentrate

in areas no more than 500 metres away from supplemental feeding places. If supplemental feeding places, by affecting local red deer density, do have an impact to bark stripping, it will be possible to detect that with the described sampling methodology.

Based on a stand map (ZGS 2007), all locations were: (a) verified whether they are located in the forest, and (b) analysed for share of spruce less than 30 cm in diameter in the total growing stock in the stand in which the location lies. If a location was outside the forest or in a stand with a spruce share of less than 10%, we shifted it to the closest stand approximately equidistant from the supplemental feeding place, where the share of spruce was over 10% or as high as possible. The probability of bark stripping damage drops sharply with tree diameter: the damage is the highest on trees with the smallest breast height diameter (5 cm), while the probability of damage to trees with a diameter of over 30 cm is very small. The procedure for the selection of sampling plot locations was thus designed to have the sampling plots in stands, where the probability of bark stripping damage was relatively big, in order to maximize the gain of information relative to the extent of the field work.

For supplemental feeding places that were less than 3,600 metres apart, some of the more distant locations were already closer to the neighbouring than to the originating feeding place. In such cases we left out the entire sampling transect. Accounting for all these criteria, 72 sampling plots on 12 sampling transects that belong to 6 supplemental feeding places were selected for the field study (Figure 1). All the sampling plots were coded and their locations entered into a handheld GPS receiver (*Garmin: eTrex Vista*), which was then used to locate the locations in field. We also made a 1:25,000 topographic map with the sampling plots in order to facilitate their positioning.

DATA COLLECTION AND PREPARATION
ZBIRANJE IN PRIPRAVA PODATKOV

The research was primarily designed to study the impact of winter supplemental feeding on the spatial distribution and extent of bark stripping damage to spruce stands. However, other studies have shown that the probability of the damage may depend on many individual (e.g. tree diameter, bark thickness, branchiness) and environmental factors (e.g. deer density, distance from forest edge, crown closure). We therefore included multiple variables (see Table 1) in the analysis in

order to increase the reliability of the results on the effects of feeding and to increase the general knowledge of the factors that affect the damage. The variable selection is based on the findings by other similar studies (ČAMPA 1986, VOLK 1999, VERHEYDEN *et al.* 2006, VOSPERNIK 2006, KIFFNER *et al.* 2008, and the sources listed therein), which were adapted to the spatial scale and objectives of this study.

Data for the analysis have been taken from two sources: (a) field measurements in the sampling plots, and (b) spatially-defined data layers, which we acquired from or prepared on the basis of previous studies (see Table 1, column Data sources).

(a) The sampling plots were located with a GPS receiver or, in the absence of a satellite signal due to the terrain obstacles, with a tape measure and compass. The applied technique
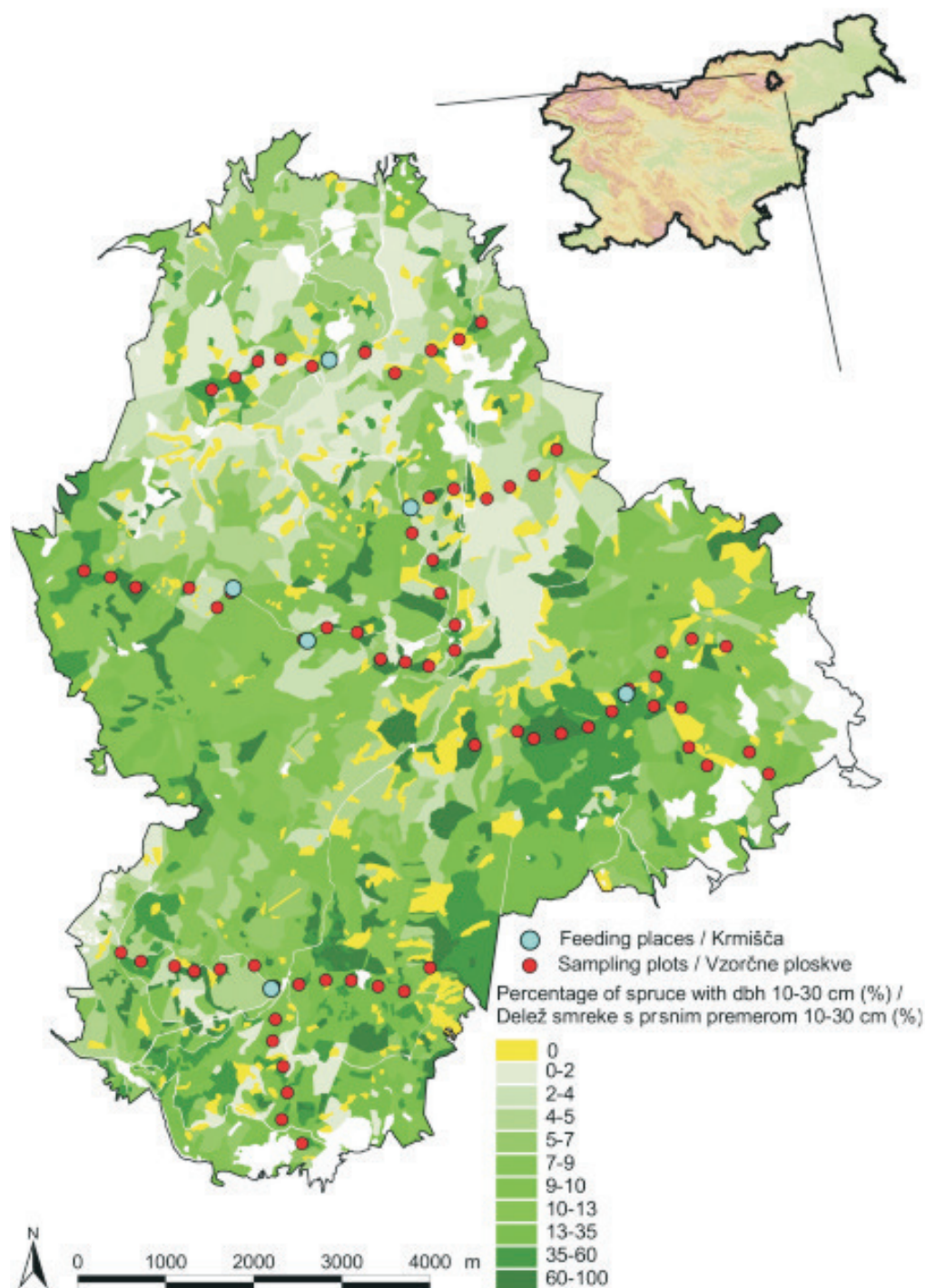

Fig. 1:   Study area and sampling plots

Slika 1: Raziskovalno območje in vzorčne ploskve

allowed for the locating of the sampling plots with a precision of a few metres or, in some instances, even a few dozen metres. However, this is sufficient for the purpose of our study, as we were studying the factors that vary across much greater distances (for example up to 1,800 metres for the feeding places). Data were acquired in the sampling plots with the use of tape measure, compass and caliper. Data were recorded starting from the centre of the sampling plot along the northern axis and proceeding clockwise. We measured all trees with a diameter at breast height (dbh) of 10 cm or more that were in the sampling plot, using as the criterion the position of the centre of the tree. For each tree we recorded the species, dbh and the maximum height and width of the wound. We did not distinguish the wounds to old and new, as there were very few fresh wounds. In the first round of measurements we measured all the trees that were less than 7.98 metres from the centre of the study area (sampling plot size of 2 ares). However, if there were fewer than 20 such trees, we increased the sampling plots to 5 ares (r = 12.62 metres). Finally, we recorded the slope and exposition, visually estimated the crown closure (in 10% increments) and recorded the size of the sampling plots (2 or 5 ares).

(b) The procedures for the preparation of other variables in the GIS environment based on existing, spatially-defined data layers is described in JERINA (2006, 2006a, 2007). It should be emphasized that the data on red deer density are relatively coarse, as the spatial resolution of the data layer from

which it was acquired is 1 km². The findings on the effect of population density are therefore rather informative. On the other hand, differences in red deer density in the study area are big (1 : 17), which is favorable in terms of the methodological detectability of density effects.

STATISTICAL ANALYSES
STATISTIČNE ANALIZE

Factors affecting bark stripping may be species-specific (VOSPERNIK 2006). Since this study deals with spruce and the share of other species in the sampling plots is therefore relatively small (12%), the analysis includes only data sets on spruce, with the individual trees (n = 2,301) being the basic statistical unit.

Correlation analysis (Kendall's tau-b) shows the existence of correlations between some of the independent variables, but even the strongest correlation (r = -0.426) is lower than the highest acceptable level of 0.85 or 0.50 that some authors (e. g. EDGE / MARCUM / OLSON-EDGE 1987) recommend for regression analysis (Table 2). All variables have therefore been included in the final regression analysis described hereinafter.

The effects of independent variables on bark stripping damage were analysed with binary logistic regression, the stepwise forward algorithm in the Windows software package SPSS 13.0. In the basic version of logistic regression the dependent variable is binary, which suits our data (damaged

Table 1: List, codes and sources of analysed variables

Preglednica 1: Seznam, šifre in viri analiziranih spremenljivk

Description of variable / Opis spremenljivke	Variable code Koda spremenljivke	Unit Enota	Source of data Vir podatkov
Altitude / Nadmorska višina	ALT	m	GURS 1995
Slope / Naklon	SLOP	°	
Intensity of solar radiation / Jakost sončnega obsevanja	SUN	MJ/m²	GABROVEC 1996
Distance to the nearest forest edge/ Oddaljenost od najbližjega gozdnega roba	EDGE	m	MKGP 2002
Red deer population density indeks / Indeks populacijske gostote jelenjadi	DEER	/	JERINA 2006
Stand basal area / Temeljnica sestoja	BASL	m²/ha	Present study Pričujoča raziskava
Tree density / Gostota dreves	TREE	N / ha	
Crown closure / Sklep krošenj	CROWN	%	
Shannon diversity index (for shares of basal areas of tree species) / Shannonov indeks pestrosti (za deleže temeljnic drevesnih vrst)	DIV	/	
Diameter of the tree* / Premer drevesa*	DBH	cm	
Distance to the nearest suplemental feeding place / Oddaljenost od najbližjega krmišča	FEED	m	
Tree damage (due to bark stripping)* / Poškodovanost drevesa (zaradi lupljenja)*		binary var. binarna spr.	

* in the marked variables, the values refer to sampled trees (n = 2,301) and in others to sampling plots (n = 64) / *pri označenih spremenljivkah se vrednosti nanašajo na vzorčna drevesa (n = 2.301), pri drugih pa na raziskovalne ploskve (n = 64)*

Table 2:   Correlations between independent variables (r)

Preglednica 2: Korelacije neodvisnih spremenljivk (r)

	ALT	SLOP	SUN	EDGE	DEER	BASL	TREE	CROWN	DIV	DBH
FEED	-0.018	-0.119**	0.107**	-0.102**	0.006	-0.161**	0.013	0.057**	0.085**	-0.089**
DBH	0.013	-0.031*	-0.023	-0.117**	-0.016	0.151**	-0.284**	-0.125**	0.168**	
DIV	-0.186**	-0.089**	-0.008	-0.165**	0.020	-0.129**	-0.426**	-0.081**		
CROWN	-0.182**	0.285**	0.003	0.028	0.156**	0.216**	0.385**			
TREE	0.008	0.175**	-0.047**	0.199**	0.062**	0.227**				
BASL	0.062**	0.142**	0.008	-0.041**	0.084**					
DEER	-0.226**	0.113**	0.044**	-0.057**						
EDGE	0.257**	0.030*	-0.002							
SUN	0.217**	-0.040**								
SLOP	-0.355**									

Correlation is significant at the: 0.01 level**, 0.05 level* / *Korelacija je značilna pri tveganju: 0.01**, 0.05**

or undamaged tree), while the independent variables can be continuous, discrete or attributive. All the independent variables included in this study were originally continuous. Since we did not know the form of their relation (linear, non-linear) with the dependent variable, pairs of dependent and independent variables were first graphically examined. In one variable (distance from the forest edge), the relation was clearly non-linear. This variable was therefore discretized, while the others were left unchanged (Table 3). Discretization took into consideration the natural discontinuities in the effect of the variable and the number of units in the classes.

The odds ratios for changes to the value of the variable from its bottom to its top decile were calculated for all the variables included in the final logistic model. The odds ratio shows the odds of a tree being damaged if the value of the given variable changes from the bottom to the top decile.

RESULTS
REZULTATI

Data were recorded on 64 of the 72 designated sampling plots, as the others were inappropriate (e.g. no spruce). Of those 64, 33 measured 2 ares and 31 had an area of 5 ares, bringing the cumulative area of the sampling plots to 2.21 ha. A total of 2,648 trees were measured, 2,301 of which were spruce. On average, 35.4% of spruce or 29.8% of the total spruce basal area was damaged at least once, but the differences between the sampling plots were large: damage to spruce

Table 3:   Preparation of variables for logistic regression, and comparison of median values between damaged and undamaged trees

Preglednica 3: Priprava spremenljivk za logistično regresijo in primerjava median poškodovanih in nepoškodovanih dreves

Variable *Spremenljivka*	Response of dependent variable on variation of independent variable *Odziv odvisne spremenljivke na variiranje neodvisne spremenljivke*	**Mann-Whitney U test	
		Z	Rank / *Rang*
ALT	linear / linearen	-9.4	5
SLOP	linear / linearen	17.1	1
SUN	linear / linearen	-8.3	6
EDGE	*non-linear / nelinearen (6; 250, 360, 580, 800, 1200)	-6.1	8
DEER	linear / linearen	10.9	3
BASL	linear / linearen	8.1	7
TREE	linear / linearen	13.9	2
CROWN	linear / linearen	9.7	4
DIV	linear / linearen	-5.5	9
DBH	linear / linearen	-4.3	10
FEED	linear / linearen	-0.1	11

*number and borders (in parenthesis) of created classes in variable discretization / *število in meje (v oklepaju) ustvarjenih razredov pri kategorizaciji spremenljivke*

** differences of medians between damaged and undamaged trees / **razlike median med poškodovanimi in nepoškodovanimi drevesi*

ranged from 0% to 97%. The average spruce dbh was 21 cm; the average basal area for all tree species was 51.44 m²/ha, 86.3% of which was covered by spruce on average, varying in the sampling plots from 30.0% to 100%. Tree density in sampling plots varied from 400 to 3,500 trees per hectare, averaging 1,198 trees per hectare.

Logistic regression model predicts that the occurrence of the bark stripping depends on the values of the following 6 variables (Table 4):

• Distance to the nearest forest edge: the damage initially increases with the distance to the nearest forest edge and reaches its maximum at about 600-800 metres from the forest edge, whereupon it starts dropping. The probability of damage in the 580-800 metre belt is 10-folds higher than in the over-1,200 metre belt and about 5-folds higher than in the 250 metre belt.

• Tree density in sampling plots (TREE): probability of bark stripping rises sharply with increasing density of trees in the sampling plots; after controlling for other factors, debarking probability for example increases over 14-folds between the lowest and the highest deciles (from 720 to 3,450 trees / ha).

• Local deer density index (DEER): damage increases as deer density grows; the odds ratio between the highest and the lowest deciles of deer density (i.e. 0.5 and 8.6 animals / 100 ha) is 1 : 5.8.

• Density of solar radiation: damage drops as solar radiation grows; the odds ratio between the lowest and the highest deciles of radiation is 2.4 : 1.

• Slope (SLOP): damage increases as the terrain grows steeper; the odds ratio between the lowest and the highest slope deciles (i.e. 1° and 25°) is 1 : 3.2.

• Index of diversity of tree species in sampling plots (DIV): as the index grows, damage decreases: the odds ratio between pure spruce stands and stands with the top decile of diversity index (0.72) is 2.2 : 1.

The described logistic model correctly classifies 79.7% of all spruce trees, but the classification accuracy of negative samples (undamaged trees) is higher than that of positive samples (82.6% vs. 72.2%).

Contrary to expectations, we did not find any effect of supplemental feeding (FEED) on bark stripping damage probability. The impact of feeding was not significant, either in the logistic regression or in the analysis of equality of medians of distances of damaged and undamaged trees from the nearest supplemental feeding place (Tables 3 and 4).

DISCUSSION
DISKUSIJA

The results of this study underline the fact that bark stripping damage by red deer is a serious problem in Slovenia.

Table 4:   Variables and estimated coefficients of the fitted logistic regression model of spruce bark stripping damages

Preglednica 4: Spremenljivke in koeficienti v logističnem modelu poškodovanosti smreke zaradi lupljenja po jelenjadi

	Parameter estimate Ocena parametra	St. error St. napaka	Wald	DF SP	p-value p-vredn.	Percentil 0.05, 0.95	Odds ratio* Razmerje obetov*
*EDGE			185.5	5	0.000		
1	0.625	0.292	4.6	1	0.032		1.9
2	1.438	0.313	21.1	1	0.000		4.2
3	2.247	0.285	62.1	1	0.000		9.5
4	2.301	0.292	62.0	1	0.000		10.0
5	0.923	0.300	9.5	1	0.002		2.5
TREE	1.00E-03	9.04E-05	122.5	1	0.000	720; 3450	15.3
DEER	3.30E-03	3.92E-04	70.8	1	0.000	33; 567	5.8
SUN	-4.53E-04	7.86E-05	33.2	1	0.000	-951; 995	0.41
SLOP	0.048	0.009	27.4	1	0.000	1; 25	3.2
DIV	-1.080	0.253	18.2	1	0.000	0; 0.717	0.46
Constant	-5.096	0.356	205.4	1	0.000		

For continuous (non-discrete) variables, the odds ratio for the change of the variable from its 5th to 95th percentile ($X_{0.05} \rightarrow X_{0.95}$) are given

Za zvezne (nekategorialne) spremenljivke so podana razmerja obetov pri spremembi spremenljivke iz njenega 5. v 95. percentil ($X_{0,05} \rightarrow X_{0,95}$)

In the research area (on the sampling plots), 35% of spruce with a dbh exceeding 10 cm, or 30% of the total basal area of this tree species, was damaged. In a similar study conducted in Pohorje in 1986, the share of damaged spruce was as much as 78% (ČAMPA 1986), which indicates that the situation has been improving. However, the results of both studies are not directly comparable, as the sampling plots in the previous survey were located exclusively in the areas that were very susceptible to bark stripping. The actual differences between the two periods are therefore likely smaller. Furthermore, the established share of damaged trees in the present as well as the previous study is not representative for the entire Pohorje. Indeed, they are overestimated for Pohorje, which is a result of the non-random distribution of the sampling plots. In this study, the sampling plots were located in areas with the maximum share of spruce with a dbh of 10-30 cm, which are much more exposed to bark stripping damage. Moreover, the study was carried out in a part of Pohorje with higher red deer density.

The main objective of this study was to determine the effects of winter supplemental feeding on the spatial distribution of bark stripping damage. The study did not confirm such effects. However, it did show that damage depends on several factors, some of which can be managed. This is important from the vantage point of damage mitigation.

Logistic regression model predicts that the most important factor affecting bark stripping damage is the distance to the nearest forest edge. The effects of this variable have been observed in a similar study in a spruce forest on a low mountain range in Germany (KIFFNER *et al.* 2008). The damage increases with the distance to the nearest forest edge and reaches its maximum at about 600-800 metres from the forest edge, whereupon it starts dropping. The observed impacts may be explained with several factors. Stands closer to the forest edge may be less damaged because the micro-climate (e.g. snow cover thickness, temperature, wind) may be less changed than deeper in the forest; consequently, in extreme winter conditions red deer density is probably smaller close to the forest edge than it is deeper in the forest. Moreover, the ground vegetation (e.g. shrubs, the herb layer) may be more abundant in the edge of the forest due to greater light flux, which further reduces the pressure on tree bark. Trees along the forest edge may also be branchier, which can physically prevent bark stripping (*ibid.*). The finding that bark stripping decreases beyond 800 metres from the forest edge coincides with the results of our previous telemetry studies of the habi-

tat selection by red deer (overview in JERINA 2006). These studies have shown that red deer is an ecotonal species, which in typical winters uses both forest and open areas on daily basis. The red deer move deeper into the forest during the day, but they rarely use parts of the forest that are far from the forest edge, as they would use too much energy for the moving away and return to the forest edge.

The second most important variable in the regression model is tree density: the probability of damage in plots with the highest tree density is 14-folds greater than in plots with the lowest tree density. The analyses of median values (Table 3) similarly show that bark stripping increases with higher crown closure and basal area of the stand and decreases with increasing dbh, which also corresponds to the results of other studies (e.g. VOSPERNIK 2006). Moreover, the probability of damage is inversely related to the tree species diversity in the sampling plot, which has also been shown in other studies (VOLK 1999, KIFFNER *et al.* 2008). Bark stripping damage is thus the highest in stands with tight crown closure, low tree diameter, small species diversity and high basal area. Young, thick spruce monocultures perfectly fit these characteristics. We posit that disproportionately high bark stripping damage in such stands is a consequence of several factors. (a) In spruce monocultures tight crown closure slows down wind and reflects IR radiation, giving red deer an energetically favorable environment, as the snow cover is lower than outside and effective temperatures are higher, allowing the animals to use less energy (OZOGA 1968, PARKER / ROBBINS 1984, PARKER / ROBBINS / HANLEY 1984). As a result, in severe winters with a lot of snow thick coniferous stands are a preferred habitat for the red deer (ADAMIČ 1990). (b) In younger, thick stands tree bark is softer and therefore more palatable. Moreover, branches die and fall off sooner, which provides less physical protection for trees. (c) Such stands are almost sterile food-wise as they contain little other food but tree bark (MEHLE 1995), which leads to bark stripping. Especially in areas with harsher climate or a lot of snow, tree bark is frequent winter food item for red deer (overview in GILL 1992 and VERHEYDEN *et al.* 2006). The energy value of tree bark varies depending on species, but it typically has similar energy value and digestibility as other typical winter food resources (VERHEYDEN *et al.* 2006). Bark stripping is therefore a perfectly normal feeding pattern for red deer, which is also indicated by the deer's chisel-shaped teeth. However, eating tree bark is a time-consuming activity with which the animals cannot satisfy their energy needs. Several authors

(overview in GILL 1992, VERHEYDEN *et al*. 2006) have therefore hypothesised that bark stripping is largely a response to the temporary lack of food, which is also suggested by the results of this study.

The probability of bark stripping positively depends on terrain slope and negatively on density of solar radiation; it is significantly lower in warmer than in colder aspects. The direct mechanisms of how both factors work are not so obvious, but their effects have been also shown in other studies (e.g. KIFFNER *et al.* 2008). These effects are thus not significant only in Pohorje or a random artefact of the sampling used in this study. Some authors (*ibid*.) attribute greater bark stripping damage in steep locations to greater distances between the nodes of the branches and hence easier access to the bark. Perhaps another reason why stands in colder, steeper locations are more damaged is because the snow cover there is thicker and snow melts later, reducing the accessibility of other food. Furthermore, the bark in such locations might stay thinner and less furrowed longer. In any case, the more extensive bark stripping damages in colder compared to warmer plots is a consequence of different feeding strategies, not population density, as deer prefer to use warmer areas to colder ones in the winter (JERINA 2003, 2006).

The frequency of bark stripping damage also depends on the local red deer population density index, which in the logistic model ranks 3rd among the six explanatory variables in terms of their explanatory power. The effects of this variable are intuitively expected, as greater deer density means greater food consumption. Intriguingly, however, some surveys confirm its effects and others do not. VOLK (1999), whose analysis involved provinces in Austria, for example reports that deer density, even though its spatial variation is very big, does not affect the extent of damage. However, the damage depends strongly on the stand composition. The same author recorded the lowest bark stripping damage in Voralberg, where deer density is the highest, but unlike in other analysed provinces the stands there are mostly natural, mixed, with a diverse horizontal and vertical composition. The impact of deer density can thus be completely concealed by environmental factors, which are conditioning the carrying capacity of the environment and the feeding strategies of red deer.

Previous telemetry studies in the areas with a climate comparable to that of Pohorje revealed that deer strongly concentrate in the immediate proximity of supplemental feeding places in the winter. In the Snežnik and Javornik area, for example, annual red deer density in the 200-metre belt around feeding places was about 8-folds higher than randomly expected (JERINA 2003, 2006). A study from the same area has also shown that diversity and density of tree species saplings increases with the distance from feeding place and deer damage to saplings (% of browsed trees) decreases. Moreover, our analysis that covered the entire Slovenia and analysed a multitude of environmental factors revealed that intensity of feeding has the greatest impact on damage to saplings (unpublished data). We had therefore expected that this variable would also affect the spatial distribution of bark stripping damage, but this study has not confirmed it. There are several possible explanations. (a) Damage was caused primarily in the vegetation period, when red deer do not concentrate around supplemental feeding places. (b) Damage was caused mainly during extreme winter conditions with a lot of snow, when red deer reduce their activity to a minimum and exclusively select habitats where they can minimise energy consumption, including spruce monocultures, but stop using the supplemental feeding places (see ŠKULJ 1987, ADAMIČ 1990). The first explanation does not pass critical scrutiny, as the shape of the bark damages shows that virtually all the damage occurred outside the vegetation period. The second explanation is, however, much more likely. The closure and condition of wounds indicate that very few of them occurred in the past few years, when Pohorje did not have severe winters. The local hunters have also noticed that spruce stands do not suffer bark stripping damage every year, but only in extreme winters. (c) Past problems with debarking in Pohorje have led to the relocation of supplemental feeding places to stands that are less susceptible to damage, which may have had an additional impact on the (non-) recorded effects of supplemental feeding places (M. Kranjc, director of Pohorje hunting district, personal communication). Notwithstanding this hypothesising, we believe that using supplemental feeding in order to reduce bark stripping damage is in general not rational. Supplemental feeding has been proved to effect stronger local damage to saplings, it is expensive, it can have a negative impact on the animals' health and body condition and it can alter deer's behavioural patterns (overview in SMITH 2001, PUTMAN / STAINES 2004). Using supplemental feeding to reduce the damage may be justified only when this measure is used to lure animals into areas less susceptible to bark stripping damage (see also JERINA 2006).

Results of this study showed that bark stripping damage can be prevented / reduced either with more culling or with the transformation of stands and other environmental factors.

Aside from supplemental feeding, culling is presently the only measure used to manage the relations between game and the forest. The possibilities for reducing bark stripping through increased culling are therefore often limited. It should also be emphasised that bark stripping may change relatively dully as red deer density changes. The logistic model for example predicts that a 17-folds drop in red deer density (from 8.6 to 0.5 animals / 100 ha) would reduce bark stripping by less than 6-folds. Furthermore, this as well as other studies (e.g. VOLK 1999, VERHEYDEN *et al.* 2006) have shown that population density explains a relatively small share of the variability of bark stripping. In many areas it would be therefore more effective to prevent / mitigate the damage with the preservation or creation of an appropriate structure of stands. Since spruce monocultures are very susceptible to bark stripping and in general create many problems in forest management (e.g. bark beetles gradations), it is best not to create them at al in the first place. In the existing spruce monocultures, bark stripping may be reduced with strong thinning in earlier development phases. Increasing the light in spruce stands would increase the biomass of the herb and shrub layers (food for large herbivores), reducing the need for bark stripping. Stronger thinning would also reduce the protective effects (i.e. interception of snow in tree crowns and higher effective temperature), which make such stands attractive to deer in the winter. Furthermore, thinning, by reducing competition among trees, accelerating soil mineralization and, consequently, releasing nutrients, would probably accelerate increment growth, thereby shortening the period when trees are susceptible to damage. This is not unimportant, as this period is relatively short (see VERHEYDEN *et al.* 2006 for description of inter specific differences) and bark stripping does not occur every winter. Thinning would also speed up the furrowing and thickening of tree bark, reducing its attractiveness as food, and slow down the natural pruning, making it more difficult for deer to physically get to the bark. Thinning may entail additional costs. If it is strong, it may even reduce the volume and value increment of stands due to the slower natural pruning. However, in our case this is probably not a serious problem, as damage mitigation through thinning should be carried out in earlier development stages, when the trees have a dbh between 5 cm and 25 cm. Finally, inaction may also be expensive, perhaps even the most expensive option, as bark stripping damage can substantially reduce the value of stands.

POVZETEK

Poškodbe sestojev, ki jih zaradi prehranjevanja z drevesno skorjo (tj. z lupljenjem in grizenjem skorje) povzročajo jelenjad in nekatere druge vrste velikih rastlinojedcev, so v mnogih delih sveta (vključno s Slovenijo) resen ekološki in ekonomski problem. Pogosto se ga skuša reševati z zimskim dopolnilnim krmljenjem, katerega učinki pa so domala nepoznani.

V pričujoči raziskavi smo preučevali vplive zimskega dopolnilnega krmljenja in drugih individualnih (npr. premer drevesa, sklep krošenj, gostota in vrstna sestava drevja) ter okoljskih (npr. gostota jelenjadi, oddaljenost od gozdnega roba) dejavnikov na verjetnost lupljenja smreke. Na Pohorju smo okoli šestih redno oskrbovanih krmišč koncentrično - na oddaljenosti od 300 do 1800 metrov - na med seboj pravokotnih radialnih transektih postavili 64 vzorčnih ploskev, velikih 2 oz. 5 arov, in na njih premerili vse drevje s prsnim premerov 10 in več cm (skupaj 2.648 dreves, od tega 2.301 smrek). Odnose med neodvisnimi (skupaj 11 spremenljivk) in odvisno spremenljivko (drevo poškodovano, nepoškodovano) smo analizirali z binarno logistično regresijo in korelacijskimi analizami.

Rezultati raziskave opozarjajo, da je kljub preteklim izvršenim omilitvenim ukrepom lupljenje po jelenjadi na Pohorju še vedno velik problem, saj je bilo poškodovanih 35 % smreke oz. 30 % skupne temeljnice te drevesne vrste. Proti pričakovanjem nismo odkrili nobenih vplivov krmljenja na prostorsko razporeditev poškodb zaradi lupljenja, pač pa, da so te odvisne od več drugih dejavnikov, od katerih je nekatere mogoče tudi usmerjati, kar je pomembno z vidika zmanjševanja škod. Verjetnost pojavljanja škod je nelinearno odvisna od oddaljenosti od najbližjega gozdnega roba in do razdalje 500 do 800 metrov narašča, potem pa upada; poleg tega je tesno pozitivno odvisna od gostote drevja, gostote jelenjadi in nagiba terena, negativno pa od pestrosti drevesnih vrst in jakosti sončnega obsevanja (na hladnih legah je večja kot na toplih). Poškodbam so zlasti izpostavljeni mlajši gosti čisti smrekovi sestoji, saj ti zaradi prestrezanja snega v krošnjah in odboja IR-sevanja ter posledično ugodnih varovalnih in mikro-klimatskih razmer (manjša debelina pritalne snežne odeje in večja efektivna temperatura okolja) jelenjadi zagotavljajo energijsko varčno okolje in so v hudih zimah njen priljubljen habitat, v katerem pa razen drevesne skorje skoraj ni hrane. Za preprečevanje / zmanjševanje poškodb zato priporočamo

močnejša redčenja takih sestojev. Z njimi bi namreč: a) povečali količino pritalne vegetacije v sestojih (večja biomasa zeliščne in grmovne plasti), b) pospešili hitrost njihovega debelinskega priraščanja ter posledično skrajšali obdobje, ko so ti sestoji bolj občutljivi za poškodbe, c) zmanjšali njihovo varovalno vlogo (intercepcija snega, ugodna notranja mikroklima), d) pospešili brazdanje in debeljenje drevesne skorje, upočasnili pa čiščenje debel. Glede na rezultate pričujoče in drugih raziskav menimo, da je krmljenje z vidika zmanjševanja poškodb gozda učinkovito le v primeru, če z njim živali pritegnemo v območja, ki so manj občutljiva. V splošnem pa rabo tega ukrepa zaradi spremljevalnih negativnih učinkov, kot so povečane poškodbe mladja, spremenjeni vedenjski vzorci ter potencialno slabše zdravstveno stanje živali (večja možnost prenosa zajedalcev in bolezni), kot tudi zaradi visokih stroškov njegove izvedbe odsvetujemo.

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